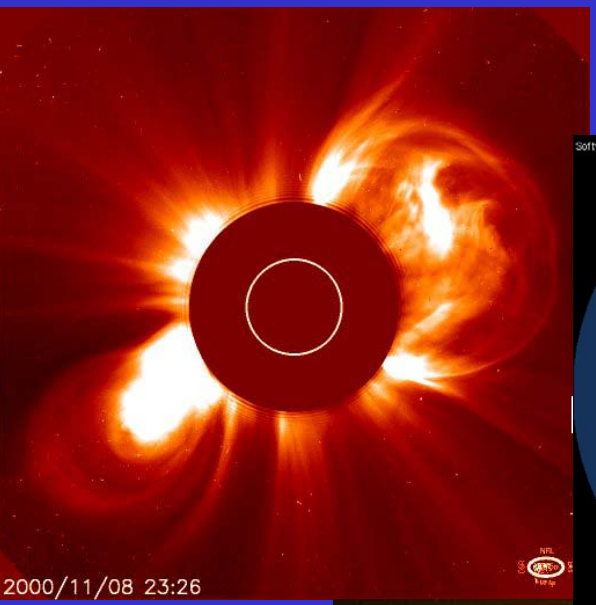
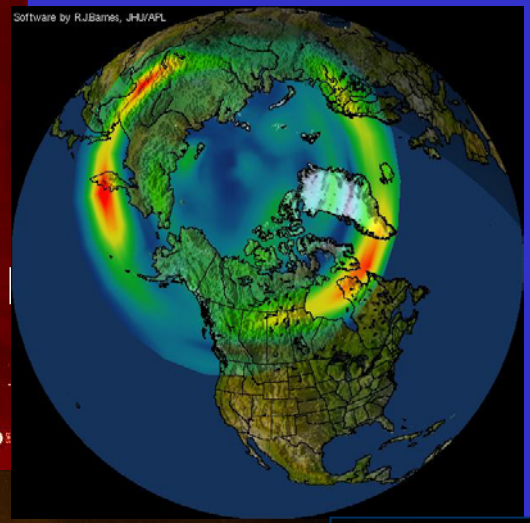
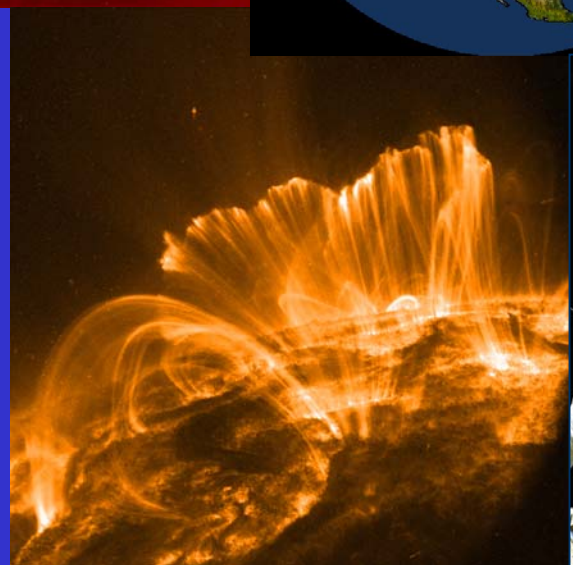
NASA's Contribution to International Living With a Star



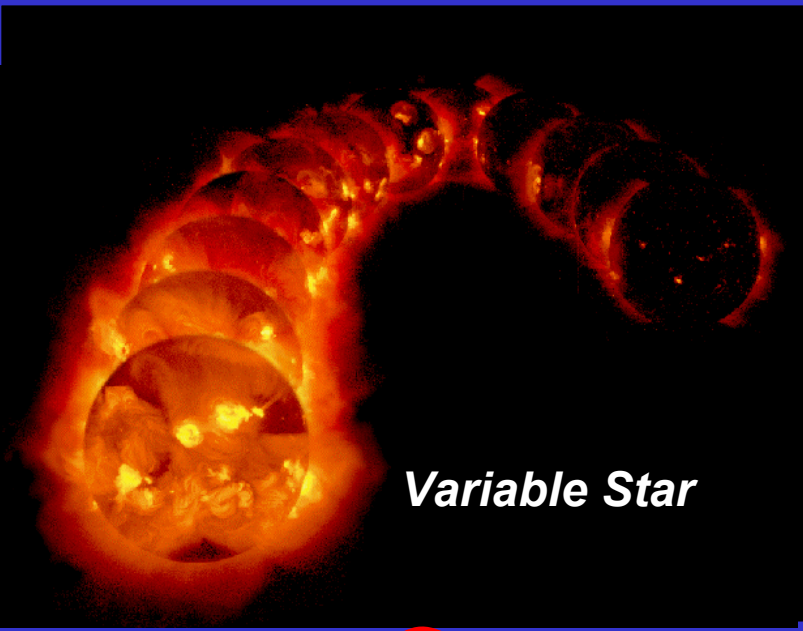


Madhulika Guhathakurta
Office of Space Science, CodeSS
NASA Headquarters

ILWS WG Meeting, Nice France
April 14-15,2003



Sun-Earth Connection (Sec) Program



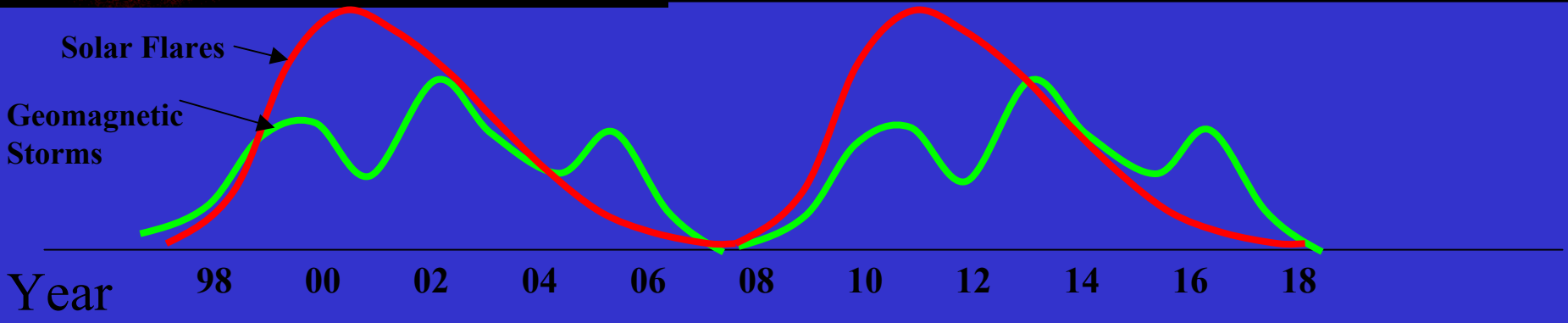
Variable Star

Varying

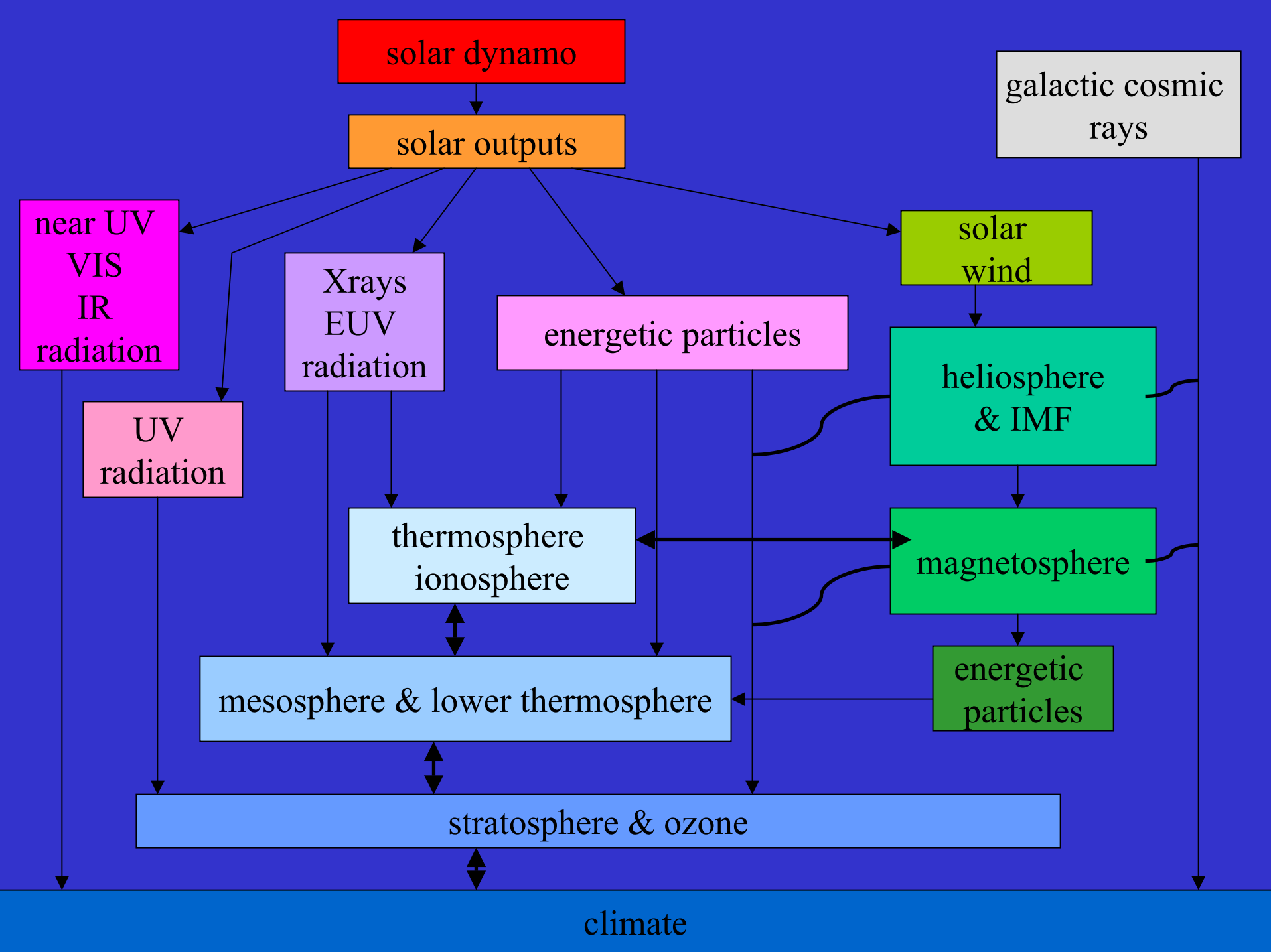
- Radiation
- Solar Wind
- Energetic Particles

Driven by 11 Year Solar Cycle

Planet



Understanding the changing Sun and its effects on the Solar System, life, and society is one of the goals of the Sun-Earth Connection Theme.


solar dynamo
solar outputs
galactic cosmic rays
near UV VIS IR radiation
Xrays EUV radiation
energetic particles
solar wind
UV radiation
heliosphere & IMF
thermosphere ionosphere
magnetosphere
mesosphere & lower thermosphere
energetic particles
stratosphere & ozone
climate

SEC Program Elements

- Strategic Plans
  - 2002-03 has been important for SEC Strategic Planning
- Operating Missions
  - Currently 14 operating missions support the research program
- Program Mission Lines
  - There are two SEC mission lines:
    - Solar Terrestrial Probes (STP)
    - Living With a Star (LWS)
- Cross-Divisional Mission Lines
  - There are two mission lines operated for the benefit of the Office of Space Sciences:
    - Explorer Mission Line
    - New Millennium Technology Mission Line
- Supporting Research and Technology Program

Strategic Planning for SEC

- **National Academy of Sciences:**

"The Sun to the Earth – and Beyond An Integrated Strategy for Solar and Space Physics, 2003-2013"

Report of the NRC's Solar and Space Physics Survey Committee, L.J. Lanzerotti and J.L. Burch, 6 August 2002

- **Sun-Earth Connection Advisory Subcommittee Roadmap Document (Reviewed every two years)**

Report to the Space Science Advisory Committee, 4 September 2002

- **Office of Space Sciences Strategic Plan**

Spring 2003

- **NRC and SECAS committees validate LWS and STP flight mission scientific goals and priority**

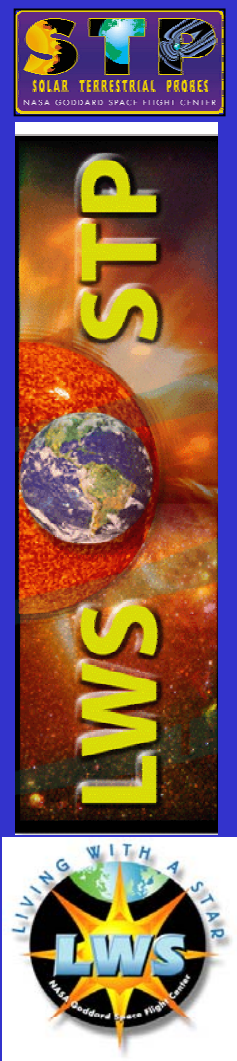
SEC Division Scientific Objectives

SEC Strategic Goal: ***Understand how the Sun, heliosphere, and the planets are connected in a single system.***

- **Explore the fundamental physical processes of plasma systems in the universe**

- **Understand the changing flow of energy & matter throughout the sun, heliosphere, and planetary environments**

- **Define the origins and societal impacts of variability in the Sun-Earth Connection**



SEC Flight Missions

- **Operating Missions**
  - **Distant Heliospheric missions**
    - VOYAGER, ULYSSES
  - **L1 *in situ* sensing missions**
    - ACE, SOHO, and WIND
  - **Solar remote sensing missions**
    - SOHO, TRACE, and RHESSI
  - **Magnetospheric/Ionospheric missions**
    - CLUSTER, FAST, GEOTAIL, IMAGE, POLAR, and SAMPEX
  - **Earth's Mesosphere**
    - TIMED

Indicates prime mission phase

Relationship of SEC Primary Science Objectives to the STP and LWS Strategic Programs

Explore the fundamental physical processes of space plasma systems

Understand the changing flow of energy & Matter throughout the Sun, heliosphere, and planetary environments

Define the origins and societal Impacts of variability in the Sun-Earth Connection

Solar Terrestrial Probes
SEC Research Mission
Cadence/Synergism

TIMED
Solar-B
STEREO
MMS
GEC
MagCon
Future STP's

Solar-helio Missions
Geospace Missions

Living With A Star
Space Weather
Research System

SDO
ITSP
RBSP
Sentinels
Future LWS
SET
TM&DA

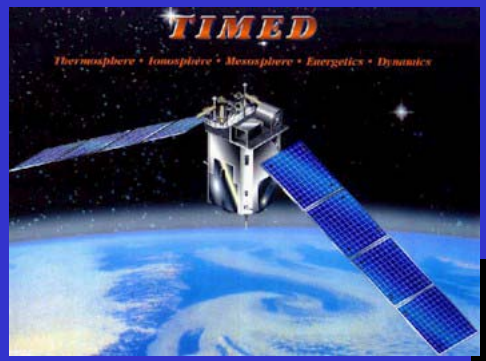
2000 2005 2010

Solar Terrestrial Probes (STP) Program

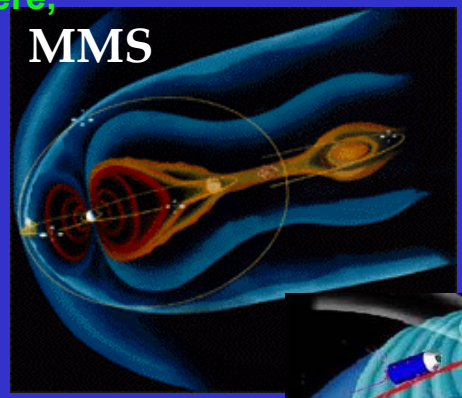
- **A strategic element of the Sun-Earth Connection Science Roadmap**
- **A continuous sequence of flexible missions designed for the sustained study of critical aspects of the connected Sun-Earth system**
- **A creative blend of in-situ and remote sensing observations, from multiple platforms, addressing focused science objectives**
- **The community-selected initial Solar Terrestrial Probes are:**
  - **Thermosphere Ionosphere Mesosphere Energetics Dynamics (TIMED) (Launched 12/07/01)**
  - **Solar-B**
  - **Solar-Terrestrial Relations Observatory (STEREO)**
  - **Magnetospheric Multiscale (MMS)**
  - **Global Electrodynamic Connections (GEC)**
  - **Magnetospheric Constellation (MC)**

Solar Terrestrial Probes (STP)

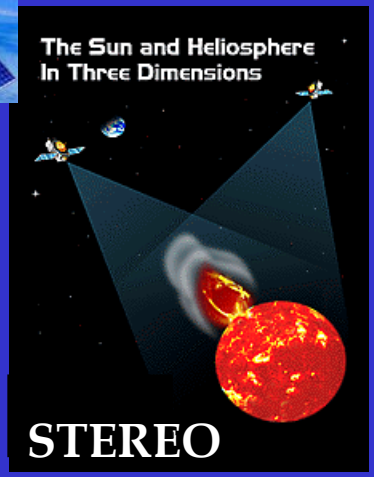
SOLAR TERRESTRIAL PROBES
NASA GODDARD SPACE FLIGHT CENTER



Determine basic structure and understand energy balance of mesosphere, lower thermosphere, ionosphere

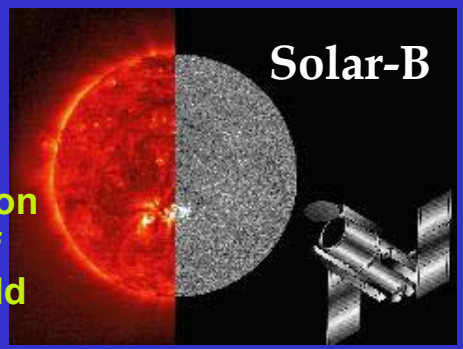


Understand fundamental plasma processes of reconnection, acceleration and turbulence



Understand origin, evolution, and propagation of CME's

Understand plasma interactions with the atmosphere



Understand creation and destruction of solar magnetic field

Understand processes that control the dynamic state and energy flow of the magnetosphere

MC

SEC LWS PROGRAM ELEMENTS

- **Solar Dynamics Observatory**
  - Three investigations selected in August 2002 for phase A development and now transitioning to phase B
- **Geospace Missions**
  - Geospace Mission Definition Team identifies the Ionospheric-Termospheric Storm Probe and Radiation Belt Storm Probe Missions as highest priority.
- **Sentinels**

  Mission architecture under study with International Living With a Star (ILWS) partners
- **Space Environment Testbeds**
  - NRA every year

  Targeted Research and Technology (aka Theory Modeling and Data Analysis)
  - NRA every year. TRT goals and priorities team selected. (report due in summer of 2003)
- **Solar Probe Mission**
  - Engineering study completed. There will be a Science Technology and Definition Team formed in Summer/Fall of 2003.

Living With A Star (LWS) Program

- A strategic element of the Sun-Earth Connection Science Roadmap
- Utilizes a systems approach to develop the scientific understanding necessary to effectively address those aspects of the connected Sun-Earth system that directly affect life and society
- Implemented by a sequence of inter-related missions
- The initial LWS strategic missions are:
  - Solar Dynamics Observatory (SDO)
  - Geospace Missions Network
  - Sentinels

The Solar Dynamics Observatory (SDO)

- **First Living With a Star (LWS) Mission, part of Sun-Earth Connection theme**
- **Will characterize the dynamic state of the Sun enhancing the understanding of solar processes and space weather. Viewed as SOHO follow-on**
- **NASA GSFC will manage the mission, build the S/C in-house, manage and integrate the instruments, develop/manage the Ground System & Mission Operations, and perform Observatory environmental testing at GSFC**
- **SDO Investigations:**
  - –Helioseismic Magnetic Imager (HMI); PI: Phil Scherrer – Stanford; Images the Sun's helioseismic and magnetic fields to understand the Sun's interior and magnetic activity
  - –Solar Heliospheric Activity Research & Prediction Program (SHARPP); Atmospheric Imaging Assembly (AIA) & Guide Telescope (GT) and White light coronagraph (KCOR); PI: Russ Howard – NRL; Images the corona to link changes to surface and interior changes
  - –Extreme Ultraviolet Variability Experiment (EVE); PI: Tom Woods – LASP, Univ. of CO; measures the solar extreme ultraviolet (EUV) irradiance to understand variations
- **August 2007 EELV launch from KSC into GEO-Transfer Orbit (GTO), circularize to GEO-Sync Orbit, inclined 28.5 degrees**
  - –Provide continuous high rate data (150 Mbps) stream to dedicated ground station
  - –Spacecraft: robust, three-axis stabilized, solar-tracking with low jitter
- **Design Drivers: Continuous high data rate/volume, Geosynchronous orbit (mass to orbit, radiation), 5 year mission life, Instrument pointing and stability**

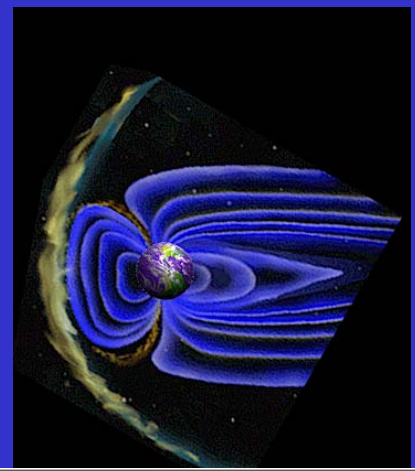
The Geospace Missions Network

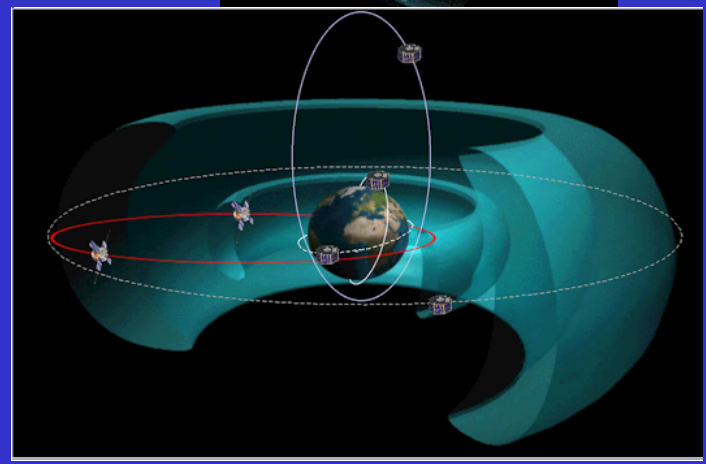
Goal

Increase scientific understanding of how the Earth's ionosphere and magnetosphere respond to changes due to solar variability

Focus areas

- **Radiation belts**
  - **Origin and dynamics of the radiation belts**
  - **Evolution of the radiation belts during magnetic storms**
- **Ionosphere**
  - **Effects of changes in ionizing radiation on the ionosphere**
  - **Variations of neutral density and drag, plasma density and drifts, *scintillations, auroras, and winds***





The Solar Sentinel Missions

Goal

Understand the transition and evolution of eruptions and flares from the Sun to the Earth's magnetosphere

Focus areas

- ***Determine the structure and long-term climatic variations of the ambient solar wind in the inner heliosphere***
- ***Determine how geo-effective solar wind structures propagate and evolve in the inner heliosphere***
- ***Determine what solar dynamic processes are responsible for the release of geo-effective events***
- ***Determine how and where energetic particles are released and accelerated***

Status

- ***Mission architecture under study with International Living With a Star (ILWS) partners***
- ***Launch – TBD***

SET Overview

Objectives

Improve the engineering approach to accommodation and/or mitigation of the effects of solar variability on spacecraft design and operations

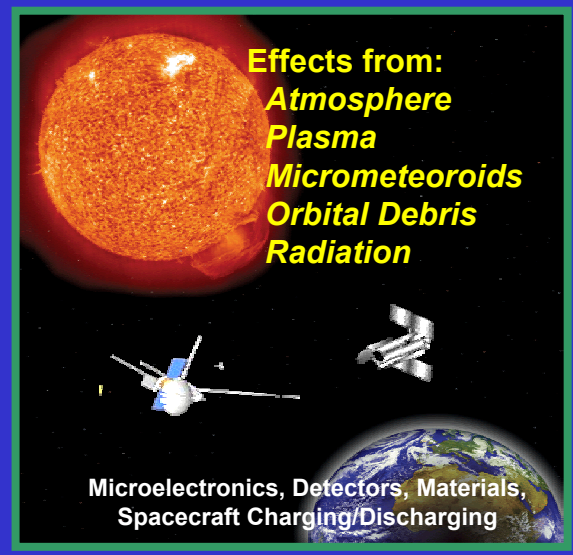
Goals

Apply results to advanced spacecraft subsystems and detector and instrument systems to achieve Space Science objectives

Leverage opportunities with Aerospace Technology Enterprise, industry, and other agencies

Transfer capabilities to industry and other government agencies

Engage public interest in Sun-Earth Connection science by showing direct relevance to daily use of technology



- Implemented as missions of opportunity via cost-sharing partnerships with various international and defense partners
- SET-1, tentatively planned to launch on DMSP in late 2005/early 2006. Formal agreement for DMSP launch being worked
- NRA for SET experiments released by HQ September 17; proposals received December 18
- Additional SET flights planned approximately every 2 years as funding permits

System-wide Approach

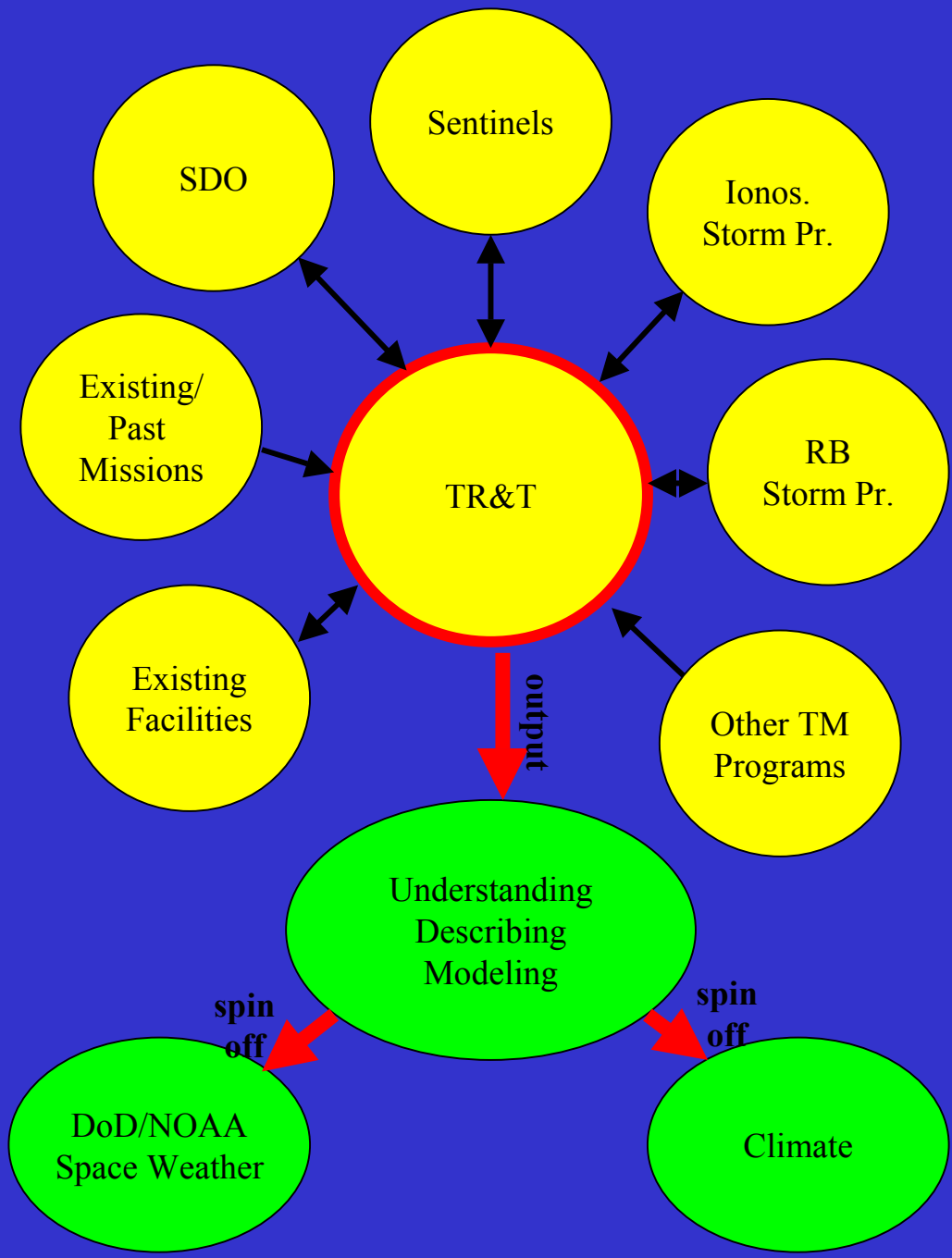
- LWS is a sophisticated program focusing not on any one region of space, but instead on our Sun Earth Region as one System
- A very important part of LWS is the study of the connection between the regions and how one drives a response in another

Science Application

- The main goal of the LWS Program is to understand "*how solar variability affects humans and technology*"
- This takes basic science research, which leads to further understanding, and in turn can be adapted to operations to improve nowcasting and forecasting

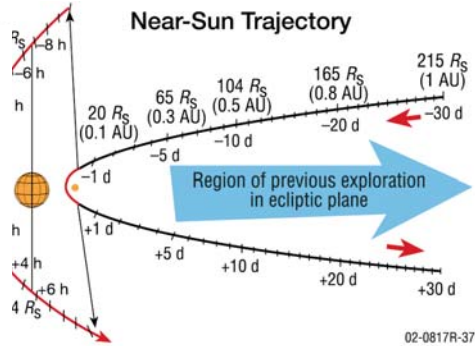
LWS Output

"Models must be seamlessly linked and new ideas and new concepts injected so that the final product is a working end-to-end model or models accurately depicting the comprehensive knowledge generated by the LWS program."


SDO
Sentinels
Ionos.
Storm Pr.
Existing/
Past
Missions
TR&T
RB
Storm Pr.
Existing
Facilities
output
Other TM
Programs
Understanding
Describing
Modeling
spin
off
spin
off
DoD/NOAA
Space Weather
Climate

SOLAR PROBE

Content: Solar Probe (SP) is humanity's ***first*** visit to our star to explore the complex and time varying interplay of the Sun and Earth which affects human activity. SP will determine ***where and what physical processes heat the corona & accelerate the solar wind to its super-sonic velocity.*** A combined remote sensing and in-situ sampling from within the solar corona itself will provide a **"ground truth"** never before available from astronomical measurements made from spacecraft in the Earth's orbit or LaGrange points.



Relevance: **1st priority** of the National Academy Space Studies Board (2002): a "large class" mission of **high importance**, providing vital contributions to NASA's Space Science strategic goals. The Solar Probe Mission will contribute to:

(I) **Understanding and protecting our home plane,** by providing new physical insight into mechanisms linking the Sun-Earth System.

(II) **Exploration of the universe**, by ***characterizing*** and investigating the solar system (from 4 solar radii to Jupiter's orbit at 5 AU) near the central star, the Sun.

(III) I**nspiring the next generation of explorers** by ***completing the reconnaissance of the solar system***, via a scientifically compelling and technically sophisticated mission. SP will discover and communicate new knowledge, not only of cultural and intellectual value, but also of political and economic value.

Measurement Strategy

- **In-situ instruments:** Solar wind electron & ion composition, magnetometer, energetic particle composition, plasma wave sensor, & fast solar wind ion detector, dust monitor
- Characterize the solar wind within a high-speed stream
- Characterize the plasma in a closed coronal structure and probe the sub-sonic solar wind
- Characterize the changes in the solar wind during the cruise from Jupiter to the Sun during extreme conditions of solar variability
- Characterize plasma waves, turbulence, and/or shocks that cause coronal heating
- **Remote-sensing instruments:** EUV and White-light imagers for field topology and context for in-situ observations
- Image the longitudinal structure of the white-light corona from the poles - a viewpoint unavailable to researchers.

Cross-Divisional Flight Mission Lines

- SEC manages two Cross-Divisional Flight Mission Programs
- New Millennium missions develop and flight validate innovative technology
- Explorer Missions target at augmentation of Code S program with SMEX and MIDEX missions.
- Both New Millennium and Explorer missions proposed from SEC experimenters have been selected for investigation.

New Millinium Technology

- **ST - 5**

ST- 5 is a technology development mission aimed at flight validation of new spacecraft techniques required for the development of mullti-spacecraft missions such as the STP Mag Con mission.

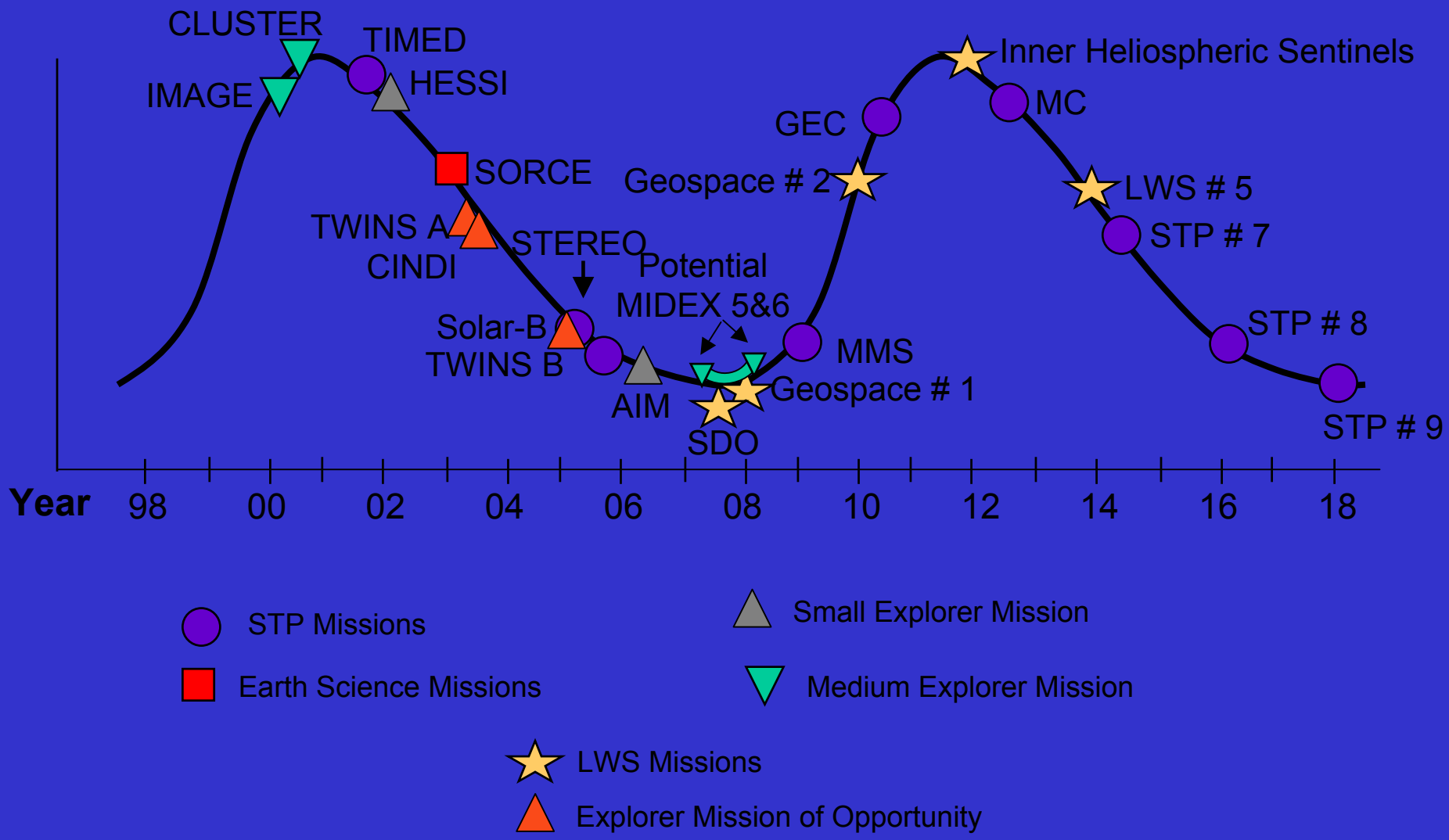
SEC Explorer Missions

- **Two MoOs in development**
  - **CINDI - Ionospheric experiment on C/NOFS) satellite**
  - **TWINS- Two-s/c ENA imager experiment**

- **THEMIS – SMEX Phase A Study**
  - magnetic substorm investigation

- **AIM - SMEX Phase A Study**
  - **Polar mesospheric cloud investigation**

SEC Strategic Plan

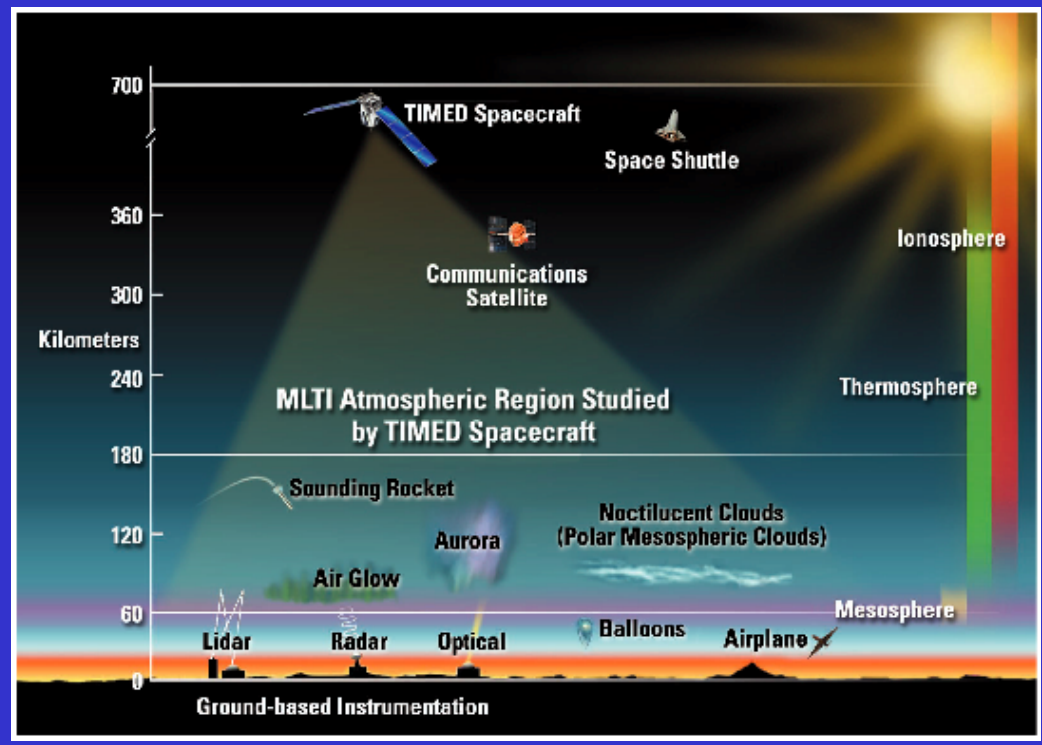


Back up slides

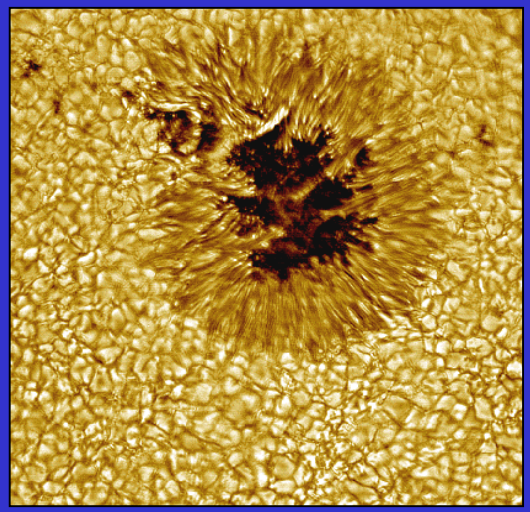
Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) Project

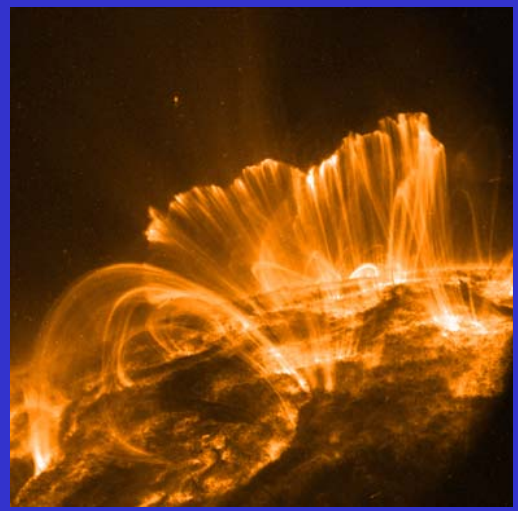
Science Objectives

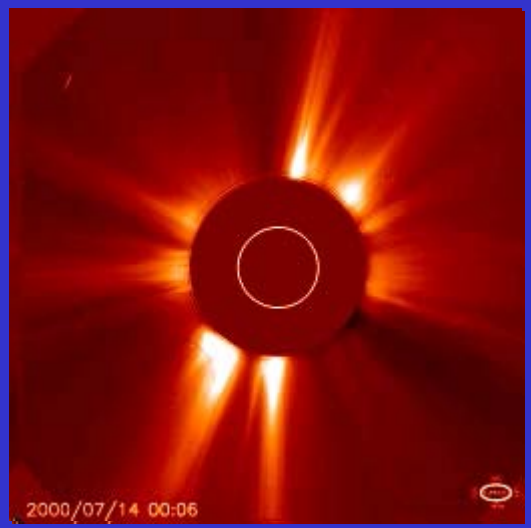
- **Global investigation of MLTI region between 60 - 180 km.**
- **Temperature, pressure, chemical composition, winds, energy inputs and outputs.**
- **Four Principal Investigators**
- **Six Interdisciplinary Investigators**
- **National Science Foundation/CEDAR ground-based Collaborative Investigators**
- Launched December 7, 2001

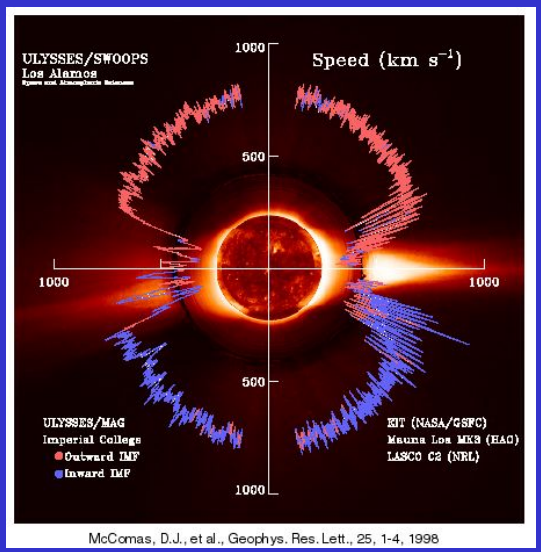


SOLAR AND HELIOSPHERIC MISSIONS IN DEVELOPMENT AND FUTURE MISSIONS









McComas, D.J., et al., Geophys. Res. Lett., 25, 1-4, 1998

Solar-B: How is solar magnetic field created and destroyed?

STEREO: What causes CMEs and how do they evolve and propagate?

Solar Probe: How is the solar corona heated and the solar wind accelerated?

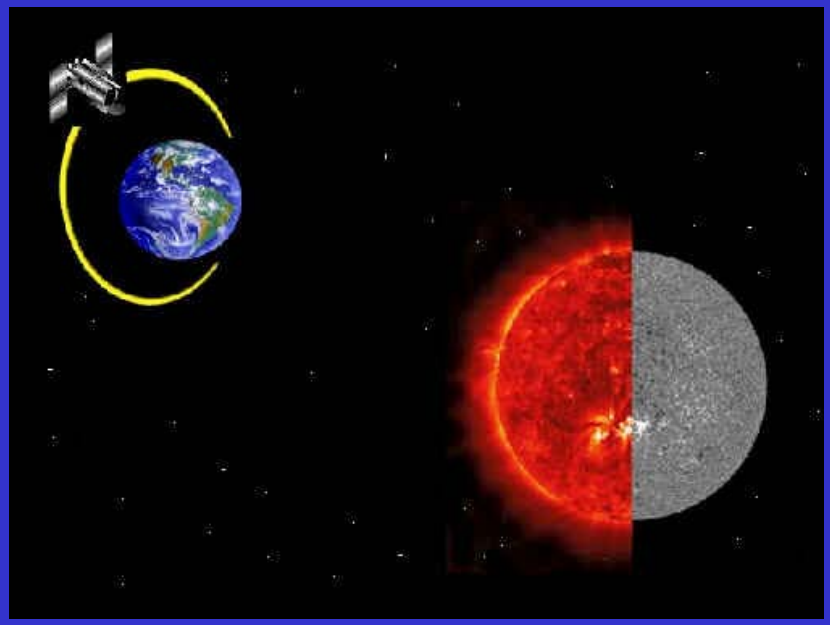
SOLAR-B

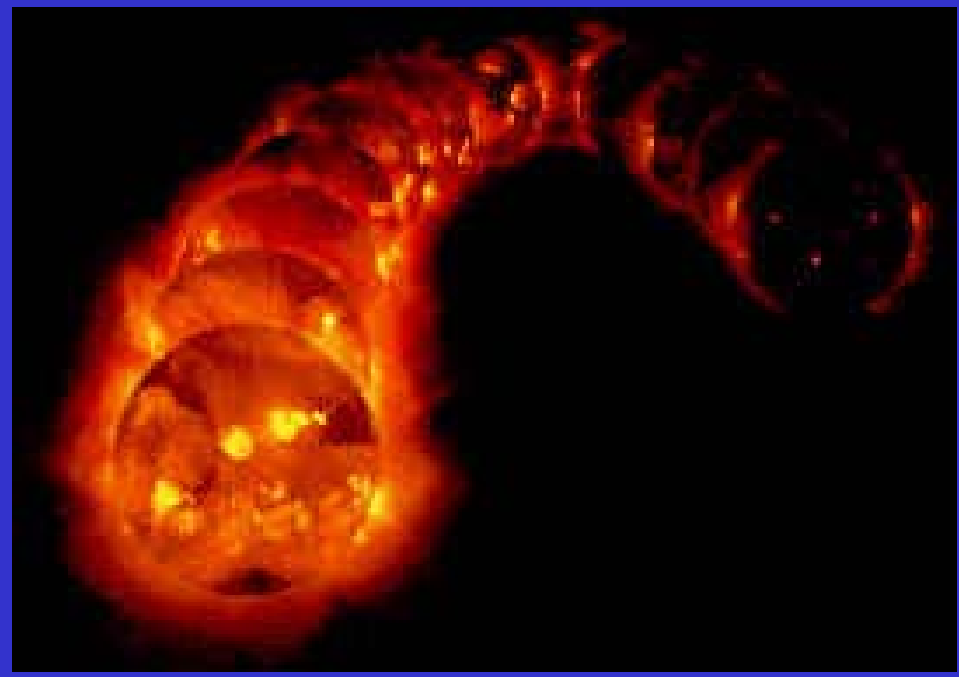
Solar-B will reveal the mechanisms of solar variability

- Determine the solar origins of space weather and global change

- Solar-B will be a comprehensive case study of stellar magnetic fields

- New view into the magnetic dynamics of the plasma universe





- ISAS mission with US instrument participation

- Solar-B will be launched on a Japanese MV rocket into a 600 km circular, 97º inclination, Sun-synchronous orbit for full-time solar observation

SOLAR-B

Solar-B Firsts:

• High-resolution continuous measurements of B and V

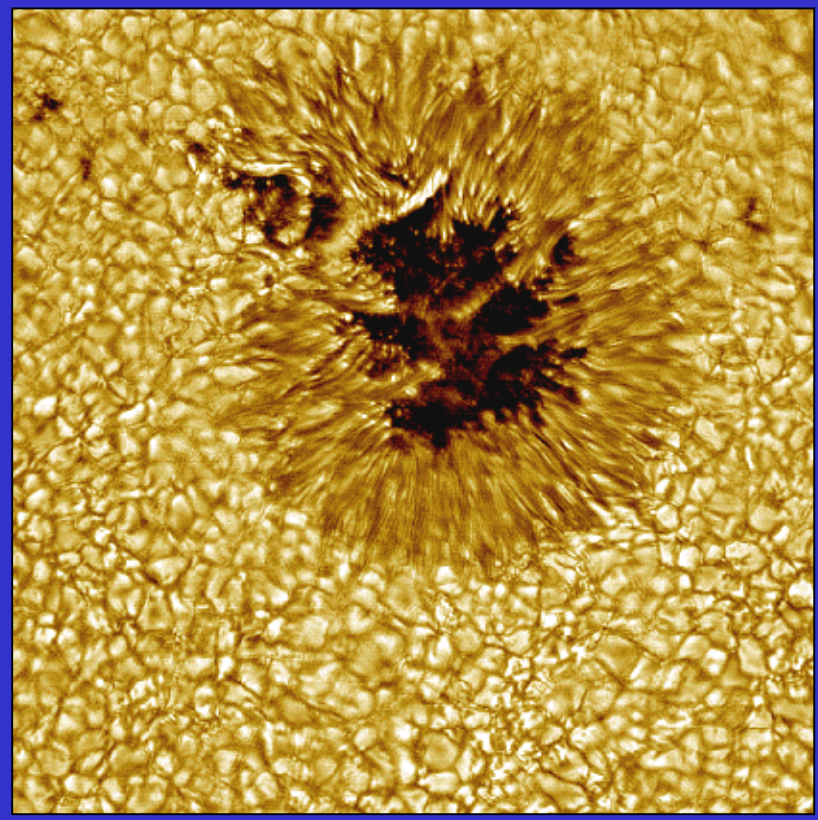
- 0.2" (factor of 10 better than ground or MDI)

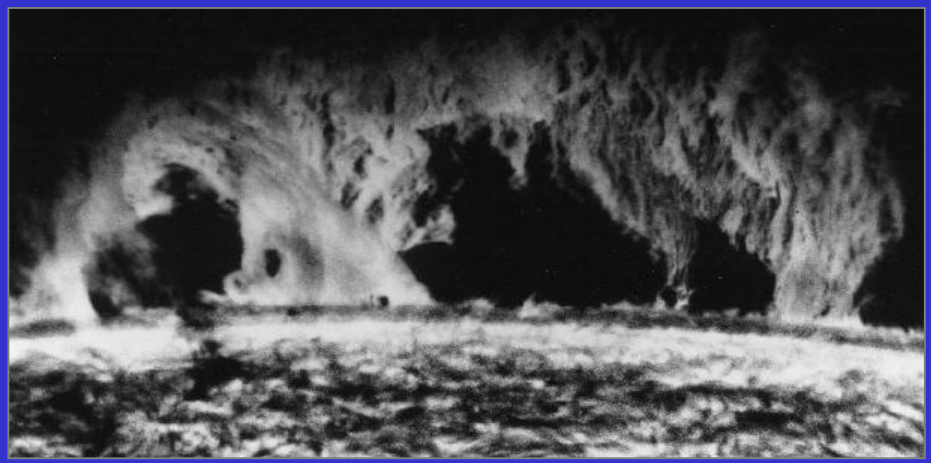
•First ever accurate measurements of vector field

- 30 -50 G sensitivity, first ever from space
- factor of 10 better than ground

• Simultaneous measurements of photospheric field and coronal response

- EUV spectrograph: Velocity sensitivity 10 km/s
- XUV/X-ray images 10^4 - 10^7K





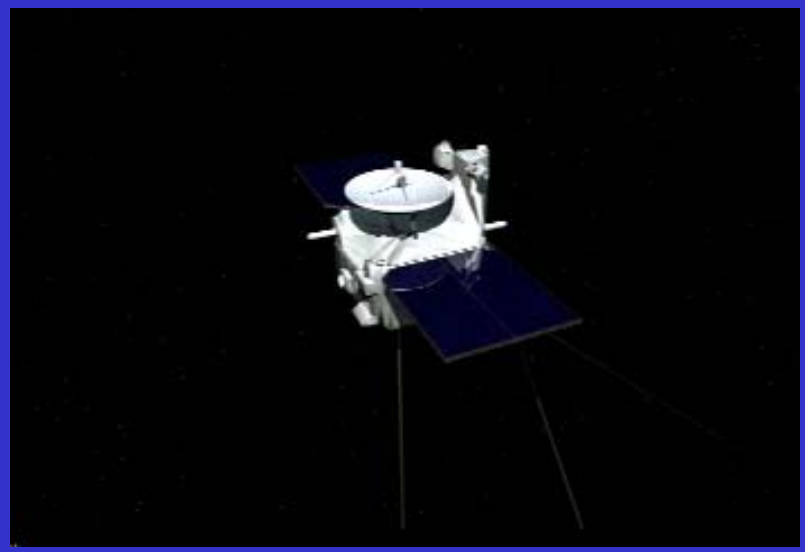
Solar-B is targeted to understand the dynamics and internal structure of the magnetic flux tubes themselves, the flux tubes that are involved in the formation, growth and destruction of all magnetic phenomena

STEREO

Coronal mass ejections are the most powerful drivers of the Sun-Earth Connection

STEREO will:

- Provide revolutionary views of the Sun-Earth system
- Trace the flow of energy and matter from the Sun to Earth
- Reveal the 3D structure of CMEs and determine their cause
- Provide unique alerts for Earth-directed CMEs



- Two identical spacecraft near heliocentric orbits at 1 AU
  - One leading the Earth
  - One lagging the Earth

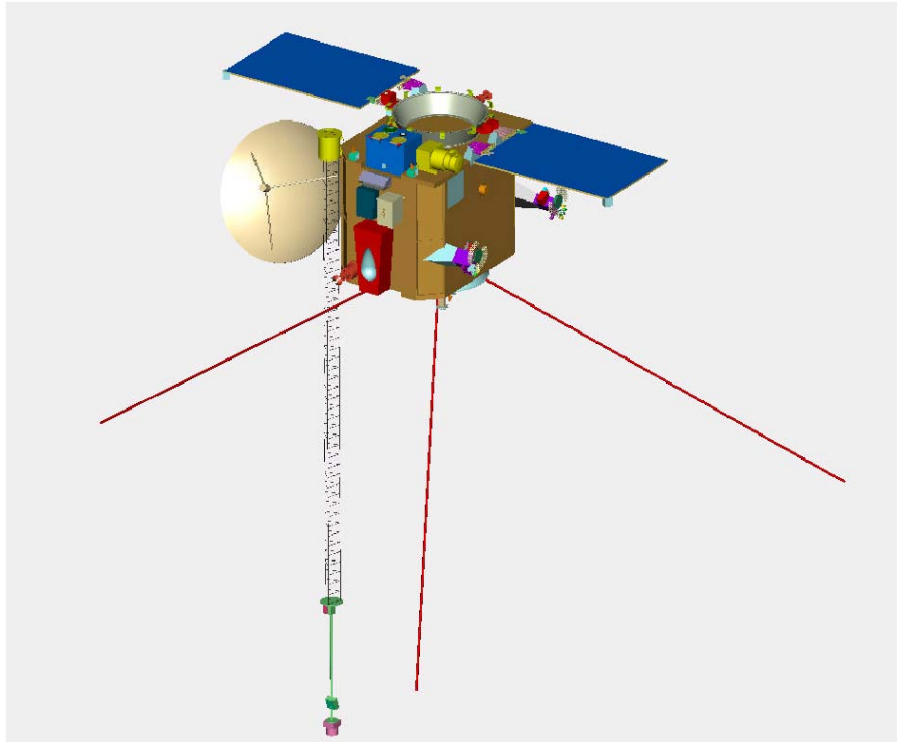
  22 degrees/year drift from Earth orbit

- Launch in November 2005

STEREO

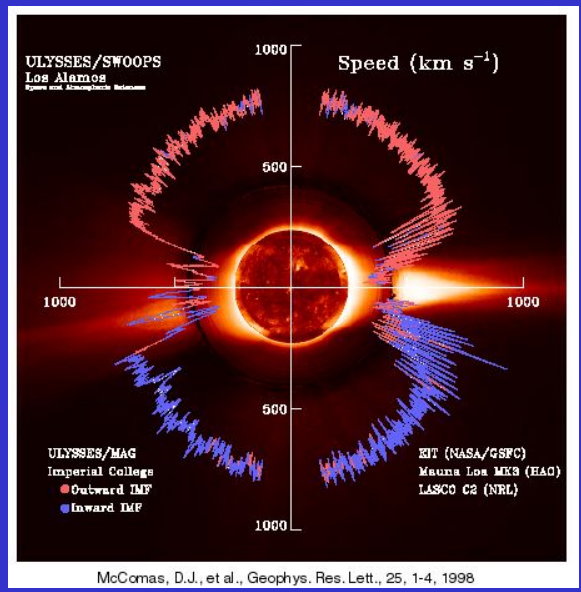
STEREO Firsts:

- First view of the Sun from out-of-Earth-orbit vantage points
- First imaging and tracking of space disturbances from Sun to Earth
- First continuous determination of interplanetary shock positions by radio triangulation
- First simultaneous imaging of solar activity with in-situ measurements of energetic particles at 1 AU



SOLAR PROBE: FIRST MISSION TO A STAR

A mission of exploration, discovery, and comprehension of the near environment of our Sun



McComas, D.J., et al., Geophys. Res. Lett., 25, 1-4, 1998

- **Science Objectives:**
  - What heats and accelerates the solar wind?
  - What roles do turbulence and waves play in the coronal heating process?
  - What are the characteristics of the structures in the polar coronal holes?

SOLAR PROBE

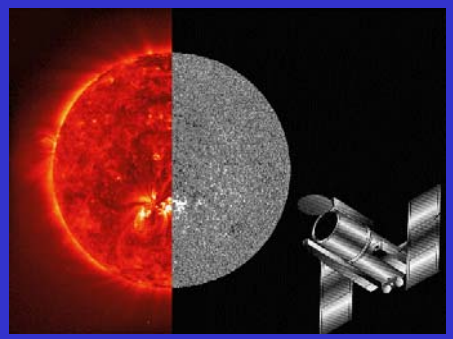
Present Status

- Science AO issued in FY00. Proposals are in. Evaluation completed.
- Three month "all solar powered" study completed on December 5, 2000 to evaluate mission without RTG; 1-pass solar power mission judged to be technically feasible, 2-pass is being studied.
- Developed mission design options compatible with available launch vehicles

QUESTS 1 & 4: OUR MAGNETIC VARIABLE STAR

Developing Missions

Physics of particle acceleration and energy release in solar flares

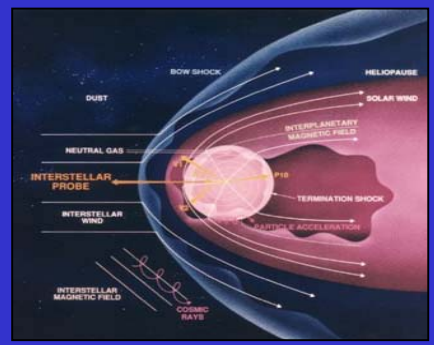


Creation and destruction of solar magnetic field

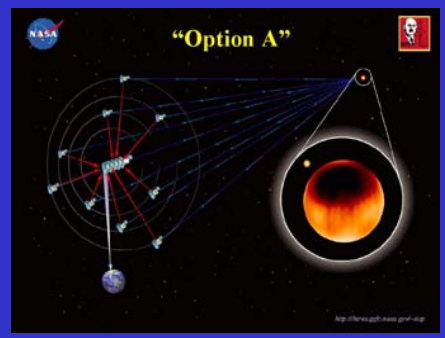
Origin, evolution, and propagation of CMEs

Future Missions

Origin of solar wind acceleration

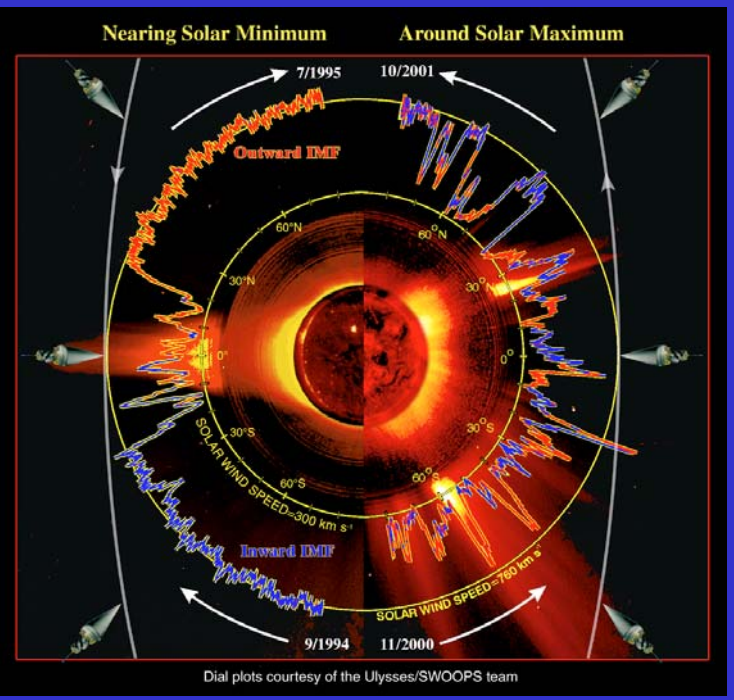


Exploration of the interstellar medium



Stellar dynamo action through the galaxy

Solar Probe

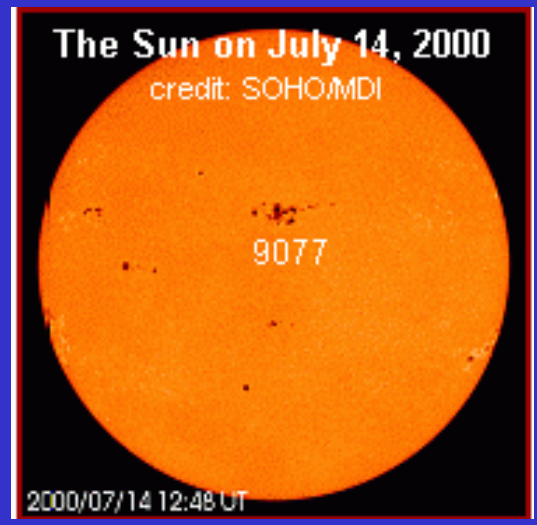


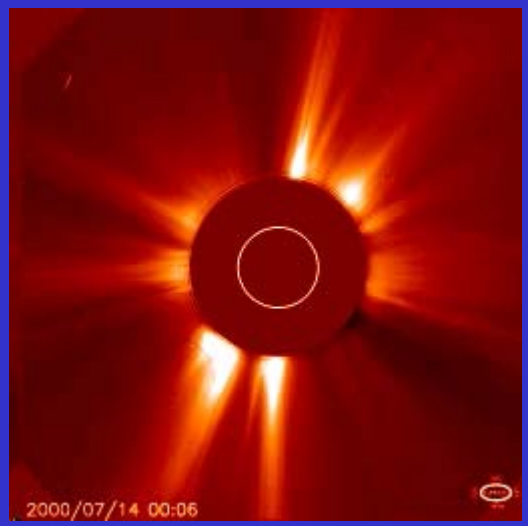
Dial plots courtesy of the Ulysses/SWOOPS team

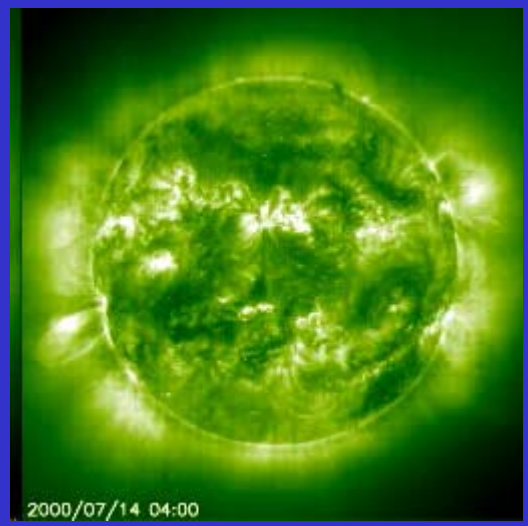
Status

- *JPL developed implementation plan during FY01*
- *FY02 President's Budget cancelled mission*
- *FY02 Congressional Budget Funded mission in FY02 only ($3M)*
  - *Mid-term progress report August 2002*
  - *Final study report with cost analysis due December 2002*
  - *Mission assigned to APL*

SOLAR AND HELIOSPHERIC MISSIONS IN DEVELOPMENT AND FUTURE MISSIONS







Above: These July 14th images of the Sun were captured by the Solar and Heliospheric Observatory (SOHO).

HESSI: What is the mechanism of rapid energy release and particle acceleration in solar flares?

Solar-B: How is solar magnetic field created and destroyed?

STEREO: What causes CMEs and how do they evolve and propagate?

Solar Probe: How is the solar corona heated and the solar wind accelerated to?

Stellar Imager: How do dynamos work in other stars?

Interstellar Probe: How does the solar system interface with the interstellar space ?

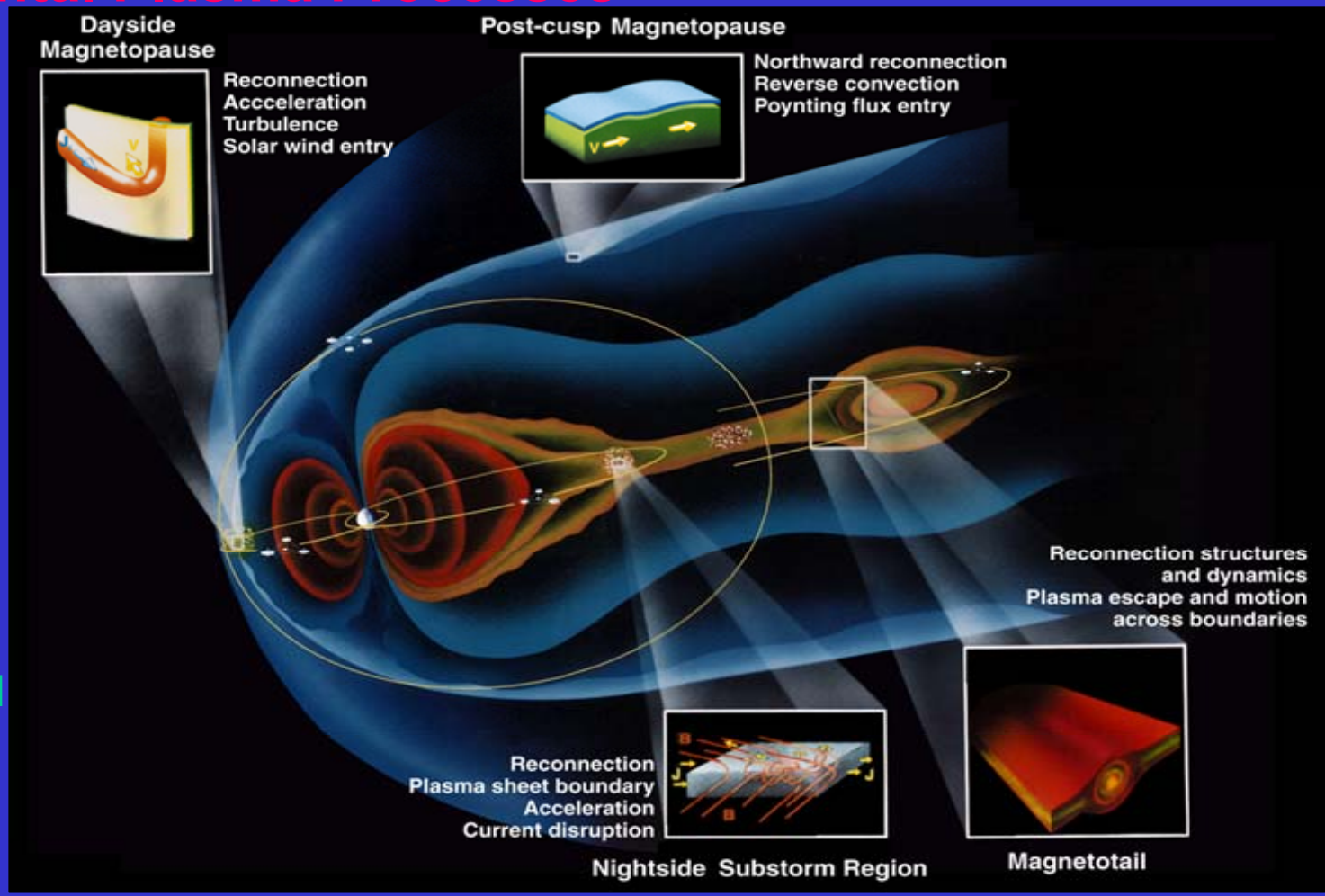
Magnetospheric Multiscale (MMS) Science Objectives

The Solar Terrestrial Probe for Understanding Fundamental Plasma Processes

- Understand the fundamental physical processes of:

  - Reconnection
  - Acceleration
  - Turbulence

AO to be released in Fall, 2002



High Energy Solar Spectroscopic Imager (RHESSI)

SMEX

Principal Investigator
Dr. Robert Lin
Univ. of California, Berkeley

Science Theme
Sun-Earth Connection (SEC)

Launch Date/Site
February 2002, KSC/ETR

Launch Vehicle
Pegasus XL

GSFC Project Manager
Frank Snow

Major Partners
Paul Scherrer Institute
Goddard Space Flight Center
University of California, Berkeley
Spectrum Astro

Science Objective

The primary objective of the HESSI mission is to explore the basic physics of particle acceleration and energy release in solar flares.

Launched February 5, 2002

Space Environment Testbed Products

Bridge the Gap Between Science, Engineering, & User Application Communities

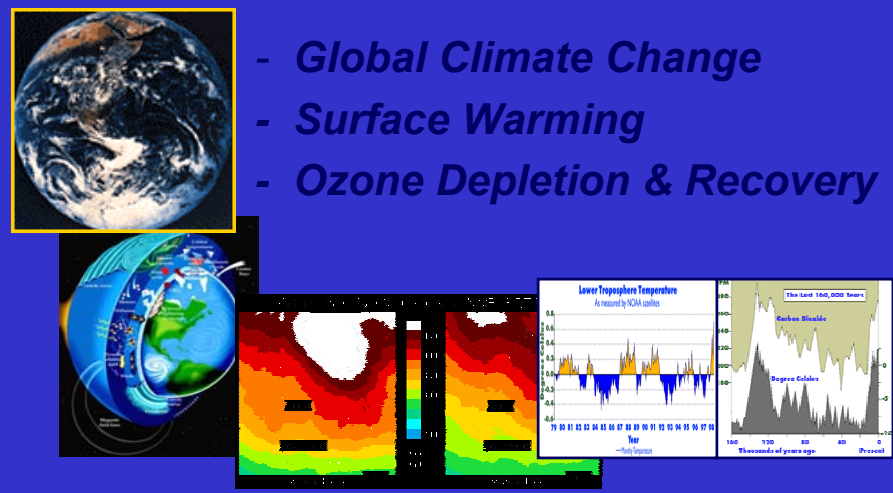
Human Radiation Exposure

- Space Station
- Space Exploration
- High Altitude Flight
- Space Utilization & Colonization

Impacts on Technology

- Space Systems
- Communication & Navigation
- Aircraft Systems
- Ground Systems

Impacts on Life & Society

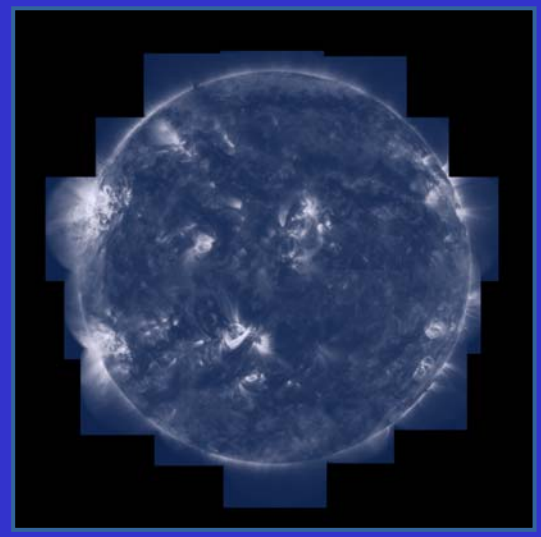


- Global Climate Change
- Surface Warming
- Ozone Depletion & Recovery

Living With A Star, Theory, Modeling And Data Analysis (TMDA)

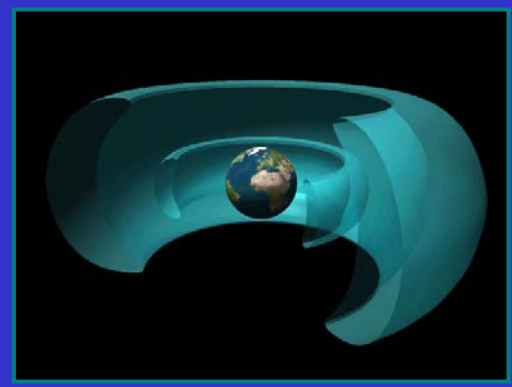
Objective

Perform research to refine the understanding of space weather physics & the role of solar variability in terrestrial climate change

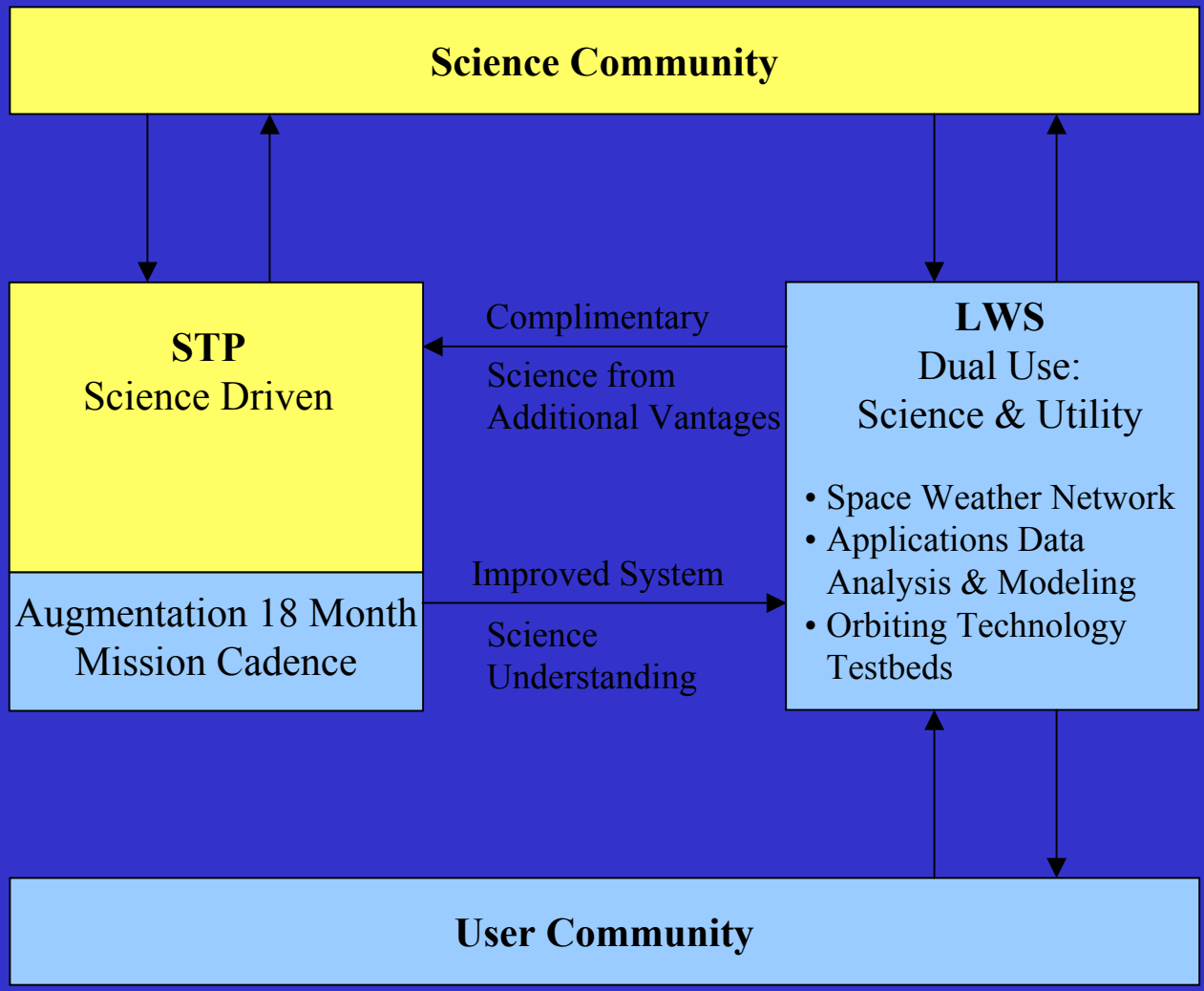


Approach

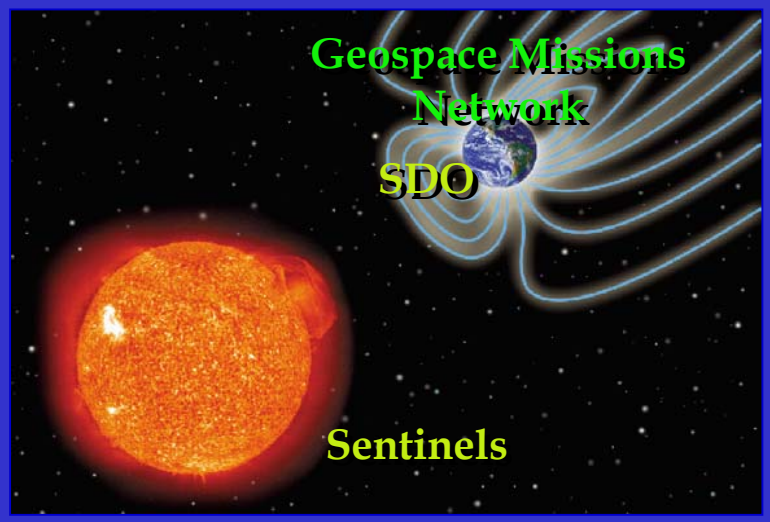
- ***Develop new instrument techniques, models, and concepts for investigating solar and geospace disturbances***
- ***Improve scientific knowledge of space environment conditions and variations over the solar cycle***
- ***Improve understanding of the effects of solar variability on long-term climate change***
- ***Improve the environment specification models & predictive capability***
- ***Issue of yearly Research Opportunities in Space Sciences (ROSS) Announcement of Opportunity***



Program Relationships
Solar Terrestrial Probes (STP) and Living with a Star (LWS)



SEC Flight Mission Programs



Current LWS Missions

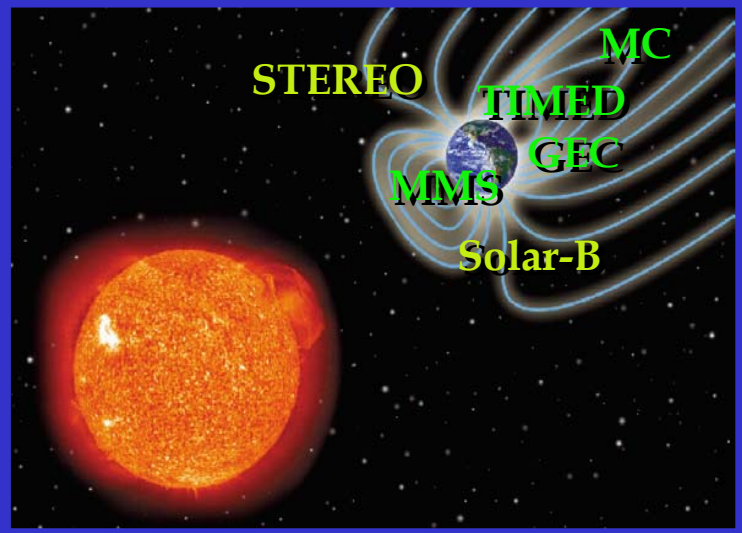
Living With a Star (LWS)

- Missions to characterize the integrated Sun-Earth System behavior and identify the critical physics that link parts of the system
- Program Elements Include:

  1) A Space Weather Research Network

  2) Theory, Modeling, & Data Analysis Program

  3) Space Environment Testbeds (SETs)



Current STP Missions

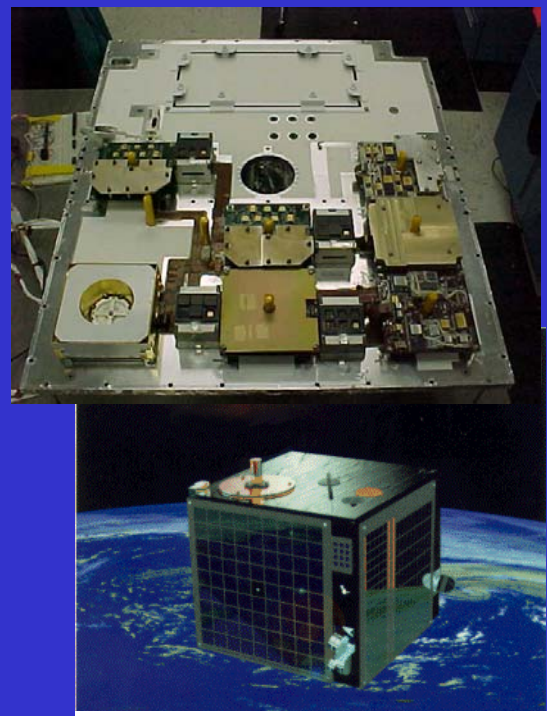
Solar Terrestrial Probes (STP)

- Missions with focused investigations to explore specific scientific research questions

Living With A Star
Space Environment Testbeds (SET)

Objective

Improve the engineering approach to accommodation and/or mitigation of the effects of solar variability on spacecraft design & operations

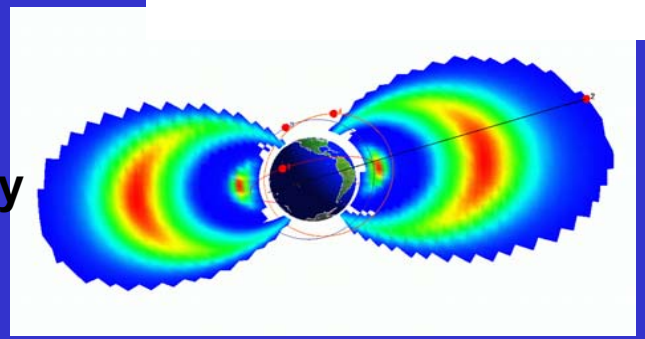


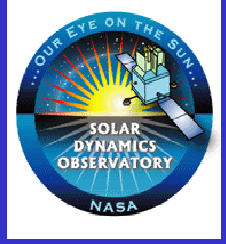
Approach

- **Collect data in space to validate the performance of new technologies & instruments for LWS science missions**
- **Collect data in space to validate new & existing ground test protocols for the effects of solar variability on emerging technologies**
- **Develop & validate engineering environment models, tools, & databases for spacecraft design & operations**

Scope

- **Spacecraft hardware & design/operations tools whose performance changes with solar variability**
- **Use flights of opportunity approach**





SDO OVERVIEW

- **First Living With a Star (LWS) Mission, part of Sun-Earth Connection theme**
- **Will characterize the dynamic state of the Sun enhancing the understanding of solar processes and space weather. Viewed as SOHO follow-on**

- **SDO Investigations:**
  - **Helioseismic Magnetic Imager (HMI); PI: Phil Scherrer – Stanford; Images the Sun's helioseismic and magnetic fields to understand the Sun's interior and magnetic activity**
  - **Solar Heliospheric Activity Research & Prediction Program (SHARPP); Atmospheric Imaging Assembly (AIA) & Guide Telescope (GT) and White light coronagraph (KCOR); PI: Russ Howard – NRL; Images the corona to link changes to surface and interior changes**

The Solar Dynamics Observatory (SDO)

Goal

Observe the Sun's dynamics to increase understanding of the nature and sources of solar variations

Focus areas

- *Origin, structure and variability of the Sun's magnetic field*
- *Relationships between the Sun's magnetic field and solar mass and energy releases*